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Adjustable Speed Drive (ASD) Feasibility Analysis

by
Douglas M. Howenstein
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Approximately half the electrical load at most Army facilities is devoted to electrical motors that operate much of the time below their rated load c. with mechanical dampers to reduce their effect. When planning either retrofit or new installations, designers and engineers must frequently determine the most economical types of drives and motors to specify for a variety of circumstances.

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13. ABSTRACT (Maximum 200 words)

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FOREWORD

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The work was performed by the Energy and Utility Systems Division (FE) of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. David Joncich is Chief, CECER-FE, and Dr. Michael O'Connor is Chief, CECER-FL.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

CONTENTS

ADJUSTABLE SPEED DRIVE (ASD) FEASIBILITY ANALYSIS

1 INTRODUCTION

Background

Approximately 50 percent of the electrical load at most Army facilities is consumed by alternating current (ac) induction motors which operate below their rated load much of the time.

Most existing heating, ventilation, and air-conditioning (HVAC) variable air volume systems run a fan at a constant speed and use some form of throttling, either inlet or outlet dampers, or inlet guide vanes, to control the air flow to conditioned spaces. These rather inefficient methods can be replaced by using adjustable speed drives (ASD) to vary the capacity of the fan without a throttling process. ASDs reduce the amount of power required by the motors, thus saving money. In addition, no motor is 100 percent efficient; all motors consume more power than they produce because they must overcome internal losses. Higher efficiency motors are now available that use less power than the current standard efficiency motors. Installation Directorate of Engineering and Housing (DEH) personnel need a quick, accurate method of determining the feasibility of using ASDs in HVAC systems.

As part of research to develop this methodology, the U.S. Army Construction Engineering Research Laboratories (USACERL) is developing ASDAPLUS, an automated ASD feasibility analysis tool designed to run on a personal computer. It will provide installation DEH engineers and others with an automated means of accurately determining the feasibility of using ASD technologies in new and retrofit designs for fan systems. The program was designed for easy use, providing as much default information as practical.

ASDAPLUS provides a quick and accurate assessment of the economic feasibility of using ASDs and high efficiency motors on fans in HVAC systems. The analysis includes determining the power and corresponding electricity cost of running the "new" system, which can be designed in one of the following configurations.

- ASD with standard efficiency motor*
- ASD with high efficiency motor
- High efficiency motor with no ASD.

ASDAPLUS provides a similar analysis of the user's current system. The results of the analyses are then compared and a financial analysis is performed to determine possible savings.

The following additional research activities are planned:

1. Testing will be conducted to measure ac induction motor heating with various ASD products, to define the actual motor life, and to quantify required derating of certain motor designs and National

* NOTE: This option is not recommended due to potential motor overheating from the nonsinusoidal voltage and current provided by the ASD. This option is mentioned here because it is not known whether all standard efficiency motors need to be derated when used with ASDs. A motor is derated to avoid damage from overheating. For example, a 50 horsepower motor might be derated by limiting the applied load to 40 horsepower.

Electrical Manufacturer's Association (NEMA) classes with the different ASD designs. Specifically, the effect of ASD carrier frequency on internal motor heating must be determined. The rotor bar design of the motor may also impact the potential need for motor derating for various ASD carrier frequency ranges and must be determined to provide the designer with accurate guidance on motor and ASD selection, sizing, and potential motor derating requirements.

2. A new type of ac induction motor called an Inverter Duty motor will be tested to determine the relative benefits of recommending this specific duty motor to replace existing motors in ASD applications. Since these motors are much more expensive than the standard motors, the results of this work will have a significant impact on the economics of ASD designs. This motor design may eliminate the need for derating and remove the concerns over motor/drive interaction and requirements for matching the motor to the ASD.

3. Commercially available ASD products will be tested to evaluate appropriate features for various types of commercial applications. With this information, more accurate ASD cost data can be developed for specific applications.

4. Data will be gathered on the relative impact of ASD product selection on the power quality of the electrical system. This data will help the designer in selecting and specifying an ASD which will not adversely affect the power quality of the facility.

5. Standard design guidance will be developed for ASD installation into conventional single speed motor applications. This documentation will include power system redesign to mitigate potential power quality problems, fire and life safety compliance, motor/drive selection and matching issues, control system redesign, and installation requirements.

Objective

The overall objective of this study is to provide guidance for installation DEHs in determining the feasibility of using ASDs in HVAC systems. This interim report discusses the procedures that ASDAPLUS employs to determine advantageous uses of ASDs.

Approach

The development approach for ASDAPLUS consisted of the following steps:

1. Ascertain the manual method of determining the amount of energy needed to operate HVAC systems, with and without ASDs.

2. Develop efficiency models for high and standard efficiency ac induction motors that account for changes in load and speed of the motor.

3. Obtain a data base of virtually all motors available in the United States. The data base contains basic motor information, such as cost and full-load efficiency, for each model.

4. Provide reasonable estimates for the annual load profile of the system being considered by analyzing data from previous USACERL studies.

5. Develop a personal computer-based automated program that incorporates the above steps, along with fan system relationships based on theoretical relationships and experimental results, that determines the economic feasibility of using ASDs in retrofit and new design.

Scope

This report discusses the procedures ASDAPLUS uses to determine the economic feasibility of using ASD technologies in HVAC systems. Issues such as motor heating and harmonics and pump applications are not addressed in this report or in the current version of the program.

Mode of Technology Transfer

The results of this research will be used to develop revisions to Corps of Engineers Guide Specification for Military Construction, CEGS 16415, *Electrical Work, Interior*, Technical Manual (TM) 5-683, *Facilities Engineering, Electrical Interior Facilities*, and Engineering Pamphlet (EP) 415-1-261, *Construction Inspectors Guide*. This work will also result in Public Works Technical Bulletins (PWTBs), an Engineering Improvement Recommendation System (EIRS) bulletin, and Public Works Digest articles on the proper selection and application of ASDs. The results will also be used to develop additional PROSPECT course materials on ASD and motor/drive applications for existing courses in electrical and mechanical engineering, including HVAC design, and fan, pump and motor design.

ASDAPLUS and an accompanying user's manual will also be released upon completion of the project. Responsibility for maintaining the software is yet to be determined.

2 NEW FEATURES

ASDAPLUS differs from all other ASD feasibility analysis programs (i.e., programs developed by Electric Power Research Institute [EPRI], Allen Bradley, General Electric, Asea-Brown-Boveri, Reliance, and Ontario Hydro) in several ways:

- ASDAPLUS provides default values for most inputs that the user may choose when the equipment's actual characteristics are unknown. The results, of course, become more accurate with the user's increased knowledge of the systems being considered.

- ASDAPLUS allows the user to avoid many fan-curve calculations and other tedious work that might reduce the user's interest in running the program.

- ASDAPLUS eliminates several inaccurate assumptions that such programs typically make:

  - the assumption that power goes to zero as flow goes to zero (it actually depends on the control point static pressure)

  - the assumption that a motor's efficiency does not change significantly at lower than rated loads

  - the assumption that one "averaged" load profile point with a corresponding efficiency rating may be used when motor efficiency is considered (efficiency does not vary linearly with load); therefore, a change in load from 100 to 90 percent has a different impact on efficiency than a change in load from 50 to 40 percent

  - the assumption that every motor's efficiency changes at the same rate as load and speed are decreased (ASDAPLUS handles high and standard efficiency motors differently)

  - the assumption that all fan types (i.e., forward-curved, backward-inclined, radial, and airfoil) require the same power at a given pressure and flow rate.

3 GENERAL APPROACH

The overall approach of ASDAPLUS is to compare the actual costs of purchasing and running each of the systems being analyzed.

ASDAPLUS starts with the system requirements, such as the design point flows and pressures, and adjusts these numbers to account for the system's particular load profile.

Next, ASDAPLUS determines the actual horsepower needed to run the fan at the different loads represented in the load profile. The efficiency of the drive and motor at the specified operating loads and speeds, along with other system inefficiencies, are considered.

The total horsepower required to run the fans is converted to kilowatt-hours, and then to dollars per year. This cost is combined with other costs, such as the initial purchase price and installation costs, to determine the total cost of the system over the life of the equipment.

This total cost is then compared to the cost of running the existing or alternate systems. Whether the system is new or a retrofit must also be taken into consideration; the economics of a motor or drive retrofit differ from the economics of a new installation.

4 PROCEDURE AND ANALYSIS

System Requirements

Finding the system requirements is the first step in analyzing an ASD application. This section of the program requires the user to enter the design point flow, pressure, and horsepower requirements of the system being analyzed. Variable air volume (VAV) systems maintain a minimum control static pressure necessary for the control boxes in the ducts to operate properly. The default value is 0.5 in. water gate (in.w.g.)* for pressure dependent control boxes and 1.25 in.w.g. for pressure independent control boxes. In addition, the full-load efficiencies of the old and new motors must be entered by the user. If these efficiencies are unknown, default values are available in a database provided by the Washington State Energy Office (WSEO) (Washington State Energy Office 1992).

Adjustments are made when the system is used in a high altitude or high temperature environment, because the static pressure generated by the fan and its required horsepower differ from what is seen at standard temperature and pressure. The adjusted flows, pressures, and horsepowers are calculated as follows:

Air Flow: $$Q_{adj} = Q_{stp} / ADR \qquad \text{[Eq 1]}$$

Static Pressure: $$SP_{adj} = ADR(SP_{stp}) \qquad \text{[Eq 2]}$$

Horsepower: $$HP_{adj} = ADR(HP_{stp}) \qquad \text{[Eq 3]}$$

where ADR = air density ratio, and is dimensionless (Carpenter 1984)
Q_{adj} = adjusted air flow in cubic feet per min (ft^3/min)
Q_{stp} = air flow at standard temperatures and pressure in cubic feet per minute
SP_{adj} = adjusted static pressure at standard temperature and pressure in in.w.g.
SP_{stp} = static pressure at standard temperature and pressure in in.w.g.
HP_{adj} = adjusted horsepower
HP_{stp} = horsepower standard temperature and pressure.

Annual Load Profile

The annual load profile, while difficult to determine exactly, is very important to the analysis since it represents the flow rates at which the system actually runs. ASDAPLUS can work with up to 24 discrete flow points. These points are considered separately until the final calculation to maintain high accuracy. The load profile requires two values for each flow point: the percent of full load and the percent of time that the system runs at that point. The percent time over all flow points must add up to 100 percent. It is acceptable to have 0 percent flow for some portion of time; this would merely indicate that the system does not operate during that percentage of time.

As an example, consider the load data presented in Table 1.

*A table of metric conversions is on p 20.

Table 1

Sample Flow Point Data

Operating Point	Percent-full Load	Percent Time
1	60	20
2	65	40
3	75	15
4	85	25

The user may select the default load profile that uses data from several administration buildings on Army installations. In USACERL Technical Report (TR) E-143, daily consumption information was acquired from Forts Carson, Belvoir, and Hood (Sliwinski et al. 1979).

A follow-up to that report, USACERL TR E-186, used this and other information in a Fourier analysis to derive equations for daily electricity consumption patterns (Sliwinski and Elischer 1983). The equations differed to account for building type and day of week.

Since this analysis requires an overall annual profile, the information in Table 1 was used to develop a typical annual load profile for an Army administration building. This profile is depicted graphically in Figure 1.

The user may also choose from the included load profile graphs that show percent-time on one axis and percent-load on the other. These graphs represent common load profiles; they are provided for users who are unsure of the exact flow rates at which a system operates but have a general idea of how it runs.

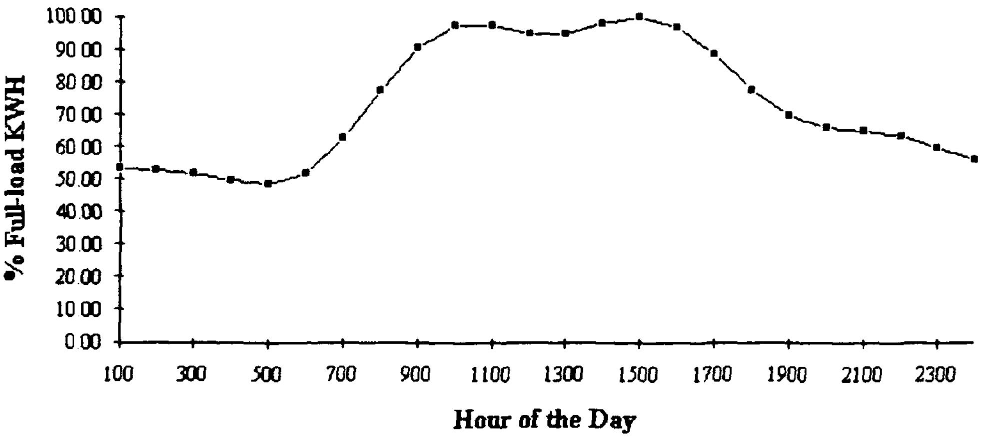

Figure 1. Annual Load Profile for Typical Administration Building.

Fan Horsepower

In this context, fan horsepower is the horsepower needed to run the fan in the system. It does not include any motor or drive inefficiencies.

For this discussion, the following variables are defined:

Q = air flow in cubic feet per minute (ft^3/min)
SP = pressure in in.w.g.
SP_c = control static pressure in in.w.g.
N = fan speed in revolutions per minute (rpm)
HP = horsepower
X_d = parameter at the design point
X^* = dimensionless parameter (X/X_d)

Three cases are analyzed: an HVAC system using outlet or discharge dampers, a system using inlet guide vanes, and a system using an adjustable speed drive. Several assumptions must be made so ASDAPLUS can perform the calculations:

1. All fans are assumed to follow the same horsepower curve regardless of size. In other words, while a fan rated at 30,000 ft^3/min will obviously require more power than one rated at 5000 ft^3/min, they are proportionately the same if they are of the same fan type.

2. Forward-curved and radial fans are assumed to require approximately the same horsepower. Similarly, backward-inclined and airfoil are assumed to require approximately the same horsepower.

3. Factors such as wheel diameter are assumed not to significantly affect the horsepower equations. This assumption is made in order to make the program more straightforward to use, since these parameters would be difficult for the user to obtain.

4. Fans from different manufacturers are assumed to have similar characteristics.

Discharge Damper

This system adheres to the Fan Laws (shown in Equations 4 through 6) with the exception that the relations must be adjusted to account for the fact that the pressure at zero flow is not zero:

$$SP_1/SP_2 = (N_1/N_2)^2 \quad \text{[Eq 4]}$$
$$Q_1/Q_2 = N_1/N_2 \quad \text{[Eq 5]}$$
$$(Q_1/Q_2)^2 = SP_1/SP_2 \quad \text{[Eq 6]}$$

where 1 and 2 represent two different operating points.

Consider the design point and any other operating point. From the above equations, one knows that SP is directly proportional to Q^2. Adding the condition that $SP \neq 0$ when $(Q=0)$ (i.e., static control pressure does not fall to zero when the air flow falls to zero), one can derive the following equation:

$$SP = a * Q^2 + b \quad \text{[Eq 7]}$$

where a and b are constants. This is a linear relationship between SP and Q^2; b is the intercept and a is the slope.

Furthermore, one can derive the following relationships:

$$b = SP(Q^2{=}0) \Longrightarrow \underline{b = SP_c} \quad \text{[Eq 8]}$$

$$a = (\text{delta } y)/(\text{delta } x) = (\text{delta } SP)/(\text{delta } Q^2) \quad \text{[Eq 9]}$$

$$\text{delta } SP = SP(Q^2{=}Q^2(d)) - SP(Q^2{=}0) \Longrightarrow \underline{\text{delta } SP = SP_d - SP_c} \quad \text{[Eq 10]}$$

$$\text{delta } Q2 = (Q{=}Qd)2 - (Q{=}0) \Longrightarrow \underline{\text{delta } Q^2 = Q_d^2} \quad \text{[Eq 11]}$$

$$\Longrightarrow a = (SP_d - SP_c)/Q_d2 \quad \text{[Eq 12]}$$

Therefore,

$$SP = [(SP_d - SP_c)/Q_d^2]Q^2 + SPc \quad \text{[Eq 13]}$$

Rearranging gives

$$SP = (SP_d - SP_c)(Q^2/Q_d^2) + SPc \quad \text{[Eq 14]}$$

Dividing by SP_d gives

$$SP/SP_d = (1 - SP_c/SP_d)(Q^2/Q_d^2) + SP_c/SP_d \quad \text{[Eq 15]}$$

This equation is now in a dimensionless form, with each variable being a percent of the design point (in other words, the design point is considered 100 percent):

$$SP^* = (1 - SP_c^*)(Q^*)^2 + SP_c^* \quad \text{[Eq 16]}$$

where $SP^* = SP/SP_d$
$Q^* = Q/Q_d$
$SP_c^* = SP_c/SP_d$

This equation allows us to determine the system static pressure at any particular operating point simply by knowing the design point pressure, design point flow, desired operating flow, and the control static pressure.

Based on the Fan Laws, the fan static pressure can be found using the following equation:

$$SP^* = (Q^*)^2 \quad \text{[Eq 17]}$$

With the desired air flow and operating fan static pressure known, the next step is to determine the horsepower that the fan will require at that point.

If done manually, the horsepower is found using the performance curves for the fan in the system being considered. For each flow point, find the fan static pressure based on equation 16, then find the corresponding horsepower value for each flow and static pressure combination.

With the assumptions discussed in Chapter 2 kept in mind, two horsepower equations were formulated to represent typical horsepower curves for fans using discharge dampers: one for forward-curved and radial fans, and one for backward-inclined and airfoil fans (Carpenter 1984). The equation for forward-curved and radial fans, in terms of flow and horsepower, is

$$HP^* = 43.755 - 0.51183(Q^*) + 1.8798e^{-2}(Q^*)^2 - 8.0556e^{-5}(Q^*)^3 \quad \text{[Eq 18]}^*$$

where $HP^* = HP/HP_d$ and $Q^* = Q/Q_d$.

The equation for backward-inclined and airfoil fans is:

$$HP^* = 43.545 - 0.77861(Q^*) + 3.1190e^{-2}(Q)^2 - 5.2778e^{-5}(Q)^3 \quad \text{[Eq 19]}$$

Adjustable Speed Drive (ASD)

For this case, system static pressure is found using Equation 16 above, and is the same as for the discharge damper case. The fan static pressure, however, is much lower than in the previous case. For adjustable speed drive applications, the fan static pressure and the system static pressure are the same. Thus, Equation 16 is used here for the fan static pressure.

With the desired air flow and operating fan static pressure known, the next step is to determine the horsepower that the fan will require at that point.

If done manually, the horsepower is found using the performance curves for the fan in the system being considered. For each flow point, find the fan static pressure based on Equation 16, then find the corresponding horsepower value for each flow and static pressure combination.

With the assumptions mentioned above kept in mind, two horsepower equations represent typical horsepower curves for fans using ASDs: one for forward-curved and radial fans, and one for backward-inclined and airfoil fan (Carpenter 1984).

The equation for forward-curved and radial fans, in terms of flow and horsepower, is

$$HP^* = -11.548 + 1.0599(Q^*) - 1.3333e^{-2}(Q^*)^2 + 1.3889e^{-4}(Q^*)3 \quad \text{[Eq 20]}$$

where $HP^* = HP/HP_d$ and $Q^* = Q/Q_d$.

The equation for backward-inclined and airfoil fans is

$$HP^* = 9.4190 - 0.10992(Q^*) + 4.0476e^{-3}(Q)^2 + 6.1111e^{-5}(Q^*)^3 \quad \text{[Eq 21]}$$

Inlet Guide Vane

For this case, the system static pressure is also calculated as in Equation 16. To calculate the horsepower values manually, the maximum flow (ft^3/min) and maximum static pressure the fan can generate at the design speed must be read from the fan's performance curve. Next, a graph must be made (based on data from the performance curve) that shows percent of maximum horsepower versus percent of maximum flow. Note that 100 percent horsepower corresponds to the design point horsepower. The system static pressure curve should then be drawn on the graph, with the corresponding operating points

* Note that none of the horsepower equations for this case or either of the following cases have any static pressure terms; this may introduce a small error in the horsepower calculations. USACERL will be investigating the relationship of a fan's horsepower to its speed and static pressure in the future. This situation should be resolved for the final version of ASDAPLUS.

being located. Finally, the percent of maximum horsepower can be read off the graph for each point. Multiplying the design horsepower by these values will get the horsepower required at each of the operating points (Carpenter 1984).

The horsepower equation used by ASDAPLUS for typical forward-curved and radial fans is

$$HP^{*} = 38.571 - 4.1667e^{-2}(Q^{*}) + 6.5476e^{-3}(Q^{*})^{2} \qquad \text{[Eq 22]}$$

The horsepower equation for backward-inclined and airfoil fans is

$$HP^{*} = 1.2405 + 2.3458(Q^{*}) - 3.6452e^{-2}(Q^{*})^{2} + 2.2778e^{-4}(Q^{*})^{3} \qquad \text{[Eq 23]}$$

Graphic Comparison of Three Cases

Figures 2 and 3 show the typical horsepower curves that are currently being used by ASDAPLUS. The savings potential of ASDs is clear.

Total Horsepower Supplied

The total horsepower supplied is the total horsepower required by the system. This is more than the horsepower required by the fan (as found above) because the motor and drive both have inefficiencies that must be considered.

Determining the total horsepower requirements of a system is a seven-step process:

1. Determine the transmission losses due to the V-belts. V-belt losses vary slightly with speed, but are approximately 5 percent of motor load.

2. Determine the actual motor efficiency at each operating point. This efficiency generally decreases as load and speed (for ASD systems) decrease.

The user may enter the efficiency if it is known. Otherwise, the user may query the WSEO Database selecting from the following search criteria: vendor, enclosure, minimum desired full-load efficiency, maximum cost, frame size, and service factor.

The program then displays all motors from the database that meet the search criteria with the motor's characteristics, the model name/number, and the catalog number.

The following comments describe how these calculations can be performed and how the data in the WSEO table were developed.

There is very little information about the effects of reduced speed on the efficiency of the motor. One source is a report from the Tennessee Valley Authority that measured the losses from a 10 HP motor to demonstrate how the efficiency of a motor changes due to a reduction in speed and load. Both high efficiency and standard efficiency motors were tested (Cathey 1986).

The data recorded from this experiment provided the efficiencies of the motors at four distinct loads (100, 75, 50, and 25 percent) and nine distinct speeds (100, 90, ..., 20 percent). A model for ASDAPLUS was developed from this information.

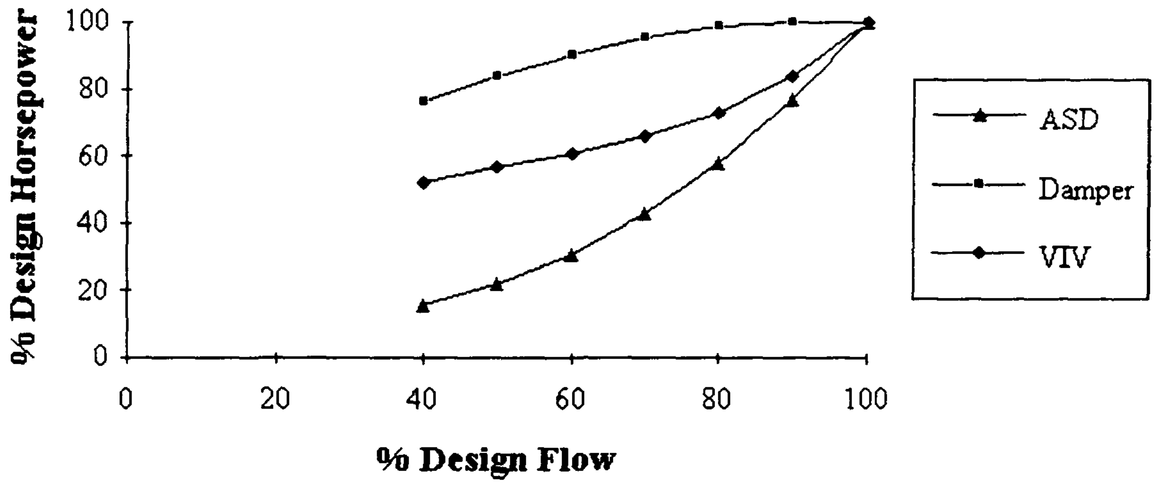

Figure 2. Horsepower Requirements for Backward Inclined and Airfoil Fans.

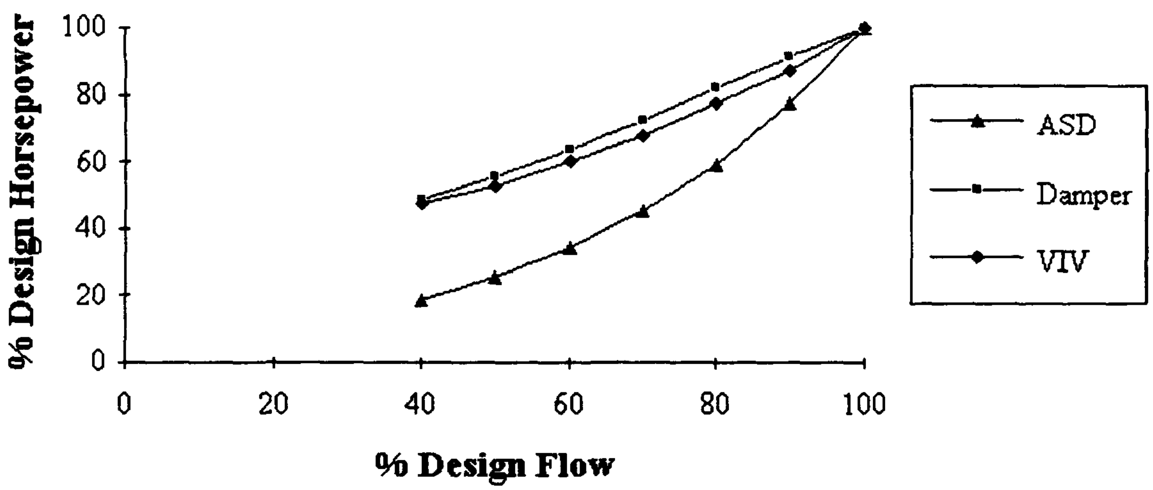

Figure 3. Horsepower Requirements for Forward Curved and Radial Fans.

The final form of the model uses the operating speed, operating load, and full-load/full-speed efficiency of the motor as inputs to the calculation of motor efficiency. The output is the computed efficiency of the motor.

The model provides, as an initial output, the loss in efficiency as a percent of the full-load/full-speed efficiency. This way, the model may be used to predict the efficiency losses of a motor when the full-load efficiency is known.

To develop the model, it was first assumed that effects of speed and load on efficiency are independent of each other. This provided a model with two separate parts. However, residual analysis of the data showed that the two variables are slightly dependent upon each other. To make this model useful, the speed factor is separated into two parts: one calculation that assumes the load of the motor has no effect on the speed portion of the model; a second calculation that accounts for the deviation due to a change in load. The load portion of the model is calculated in the same manner. The model, with its four components, provides the efficiency loss (or gain) due to a change in load and/or speed as a percent of full-load/full-speed efficiency.

For example, a 10 HP motor with a full-load efficiency of 86 percent being run at 75 percent load and 75 percent speed might see a decrease in full-load efficiency of 5 percent. This means that the actual operating efficiency of the motor is 81.7 percent.

3. Add the losses found in Step 1 and Step 2 to determine the total horsepower the motor must supply.

4. Divide the HP the motor must supply by its efficiency at each operating point to find the HP that must be supplied to the motor.

5. Determine the actual efficiency of the ASD at each operating point. This efficiency tends to decrease as speed decreases. The following equations assume that all ASDs will act the same.

For flows less than 40 percent $EFFICIENCY_{asd} = 70 + 0.4125Q(x)$ [Eq 24]
For flow from 40 to 80 percent $EFFICIENCY_{asd} = 79 + 0.1875Q(x)$ [Eq 25]
For flows greater than 80 percent $EFFICIENCY_{asd} = 86 + 0.1Q(x)$ [Eq 26]

where Q(x) = percentage of maximum air flow, x (Nadel et al. 1991).

6. Divide the HP required by the motor by the efficiency of the drive to determine the HP that must be supplied to the entire system (at each operating point).

7. Sum the individual horsepower requirements to find the total system horsepower requirements over the entire operating range. Before summing the individual operating point horsepower values, they must each be weighted by considering the percentage of the total time that each operating point represents.

Energy per Year

This phase calculates the entire system's total annual energy consumption in kilowatthours (kWh). Horsepower is first converted to kilowatthours then multiplied by the number of hours of operation:

$$\text{Energy/year} = 0.746(HP_{TOT})(8766) \qquad \text{[Eq 27]}$$

where HP_{TOT} = total system horsepower requirement
8766 = number of hours per year plus six, to compensate for leap years.

Energy Cost

This is simply the cost of electricity (in \$/kWh).

Cost per Year

The energy per year is multiplied by the energy cost to determine the total cost of electricity per year of running each system.

$$\text{Cost/year} = (\text{Energy/year})(\$/\text{kWh}) \qquad \text{[Eq 28]}$$

Savings per Year

The savings per year is the difference between the cost of running the original system and each alternative system.

Total Cost

This is the total cost of purchasing the ASD and/or high efficiency motor, including installation. The default value used for the cost of an ASD, as cited in Puttgen (1987), is:

$$ASD_{cost} = 0.07 * (HP_d)^3 - 8.29 * (HP_d)^2 + 380 * HP_d \qquad \text{[Eq 29]}$$

where HP_d is the horsepower requirement at the design point.

The default values used for the installation costs of the motors and drives are

$$MOTOR_{inst} = 10 * HP_d \qquad \text{[Eq 30]}$$
$$ASD_{inst} = 50 * HP_d \qquad \text{[Eq 31]}$$

where $MOTOR_{inst}$ = cost of motor installation (in dollars)

ASD_{inst} = cost of ASD installation (in dollars)

Two different costs could be considered, depending on whether the old system is still usable. If the old system is taken out while it still operates, the price of the new system plus installation should be used. If the old system is already out of service or must be replaced, the price used should be the price premium to be paid for the new system. The second situation will show a much faster payback, since the cost being considered is much less.

Maintenance and other hidden benefits are not considered in the analysis. For instance, while not quantified here, maintenance costs will be lower for high efficiency motors than for standard efficiency motors. This should be taken into consideration when making a final decision (Lovins 1989).

Simple Payback

Simple payback is the number of years it would take to allow the initial investment to break even:

Simple payback = (total cost)/(total savings) [Eq 32]

where simple payback is in years.

Net Present Worth

Net present worth is the total benefit of the investment minus the total cost, over the economic life of the equipment. It is adjusted to today's dollar, based on current interest and energy escalation rates.

Discounted Payback Period

Discounted payback period is the number of years it would take to allow the initial investment to break even when interest and escalation rates are considered.

Savings to Investment Ratio

The savings to investment ratio is the present worth of the savings divided by the total cost of the investment.

Life Cycle Savings

The life cycle savings analysis is a more elaborate way of determining if the considered purchase is economically viable. It shows the cumulative cash flow of the purchaser (with respect to the considered equipment) over the projected life of the equipment.

In investments where total costs exceed total savings, this cash flow analysis is known as the life cycle cost analysis.

5 CONCLUSION

USACERL is developing an automated program, ASDAPLUS, which allows the designer or engineer to do a preliminary or detailed determination of the feasibility and economics of using adjustable speed drives (ASDs) and/or high efficiency motors with fans in HVAC systems.

The automated procedures in ASDAPLUS offer several advantages over existing methods of ASD analysis used in other analysis software, including more accurate models of the motor and fan efficiencies. These improved models provide more accurate estimates of the potential energy savings and economic benefits of high efficiency motors and/or ASDs in existing or new design fan applications.

Sample annual load profiles for fan systems have been developed from actual building energy consumption data. Since it is often difficult to determine load profiles, these typical load profiles are included to minimize the time required to assess an ASD or high efficiency motor application.

Additional default and sample data are incorporated into the analysis procedure: motor and ASD efficiency as a function of speed and load; fan-type-specific performance curves (to provide accurate determination of fan power requirements over the operating range); and drive system inefficiencies.

Process control strategies for the different fan types are also defined. These refinements help ensure that the analysis results in an accurate estimate of potential energy savings and economic benefits of any selected strategy for a particular fan/motor system.

Economic analysis procedures allow use of either default cost data or (if known) actual costs for purchase, installation, and operation. The economic analysis can be as basic as the determination of simple payback or can provide life cycle savings and net present worth.

Although the analysis procedures provided in ASDAPLUS afford the user a much more accurate assessment of the energy and economic benefits of an ASD or high efficiency motor application than was previously available, additional research is underway to provide the designer with enough information to determine the long-term reliability, enhanced equipment life, and reduced maintenance potential of ASD applications.

METRIC CONVERSION TABLE

1 ft^3/min	=	.0283 m^3/min or 28.3 l/min
1 in.w.g.	=	1870 mm-Hg

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